Details of experiment:

Experiment No. 3

Aerodynamic forces and moments on a generic aircraft model

Learning Objectives:

- Use of 3D section of the 5-D wind tunnel
- Six-component Balance
- Model attitude control system
- Data acquisition system
- Estimation of aerodynamic forces acting on the model under test. The analysis involves calculation of forces and moments.
- Force data acquisition is done in order to estimate the aerodynamic coefficients for performance evaluation of the model under test.Force data is acquired using six component internal balance and is analyzed. Sign convention for forces and moments play an important role in balance data acquisition during the test and data analysis later. Balance data analysis includes forces and moments calculation in various axes system.

Apparatus:

- Six component force balance:
- Whetstone bridge card (SCXI-1000)
- Data acquisition card (PXI-1033)
- Labview software:
- Aircraft model is used to do experiment.

Precautions

1. Check the individual resistance of the bridges.

2. Check the bridge for shorts with the grounds. This should show a very high resistance of the order of mega ohms

3. DO NOT SHORT THE OUTPUT LEADS ONCE THE OOWER SUPPLY IN "ON"

4. Check the direction of the outputs by applying small loads

5. Allow the bridges to warms up for at least one hour actual measurement.

6. Check the Balance voltage which should not be exceed limit of 6-component strain gage balance.

Principle of operation and Procedure

Our aircraft modelis mounted on the balance accurately. So it transmits the load to the balance during experiment. Balance is attached to the mechanism which provides pitching, yawing and rolling moment to the aircraft model. We are using **Six component force balance which** is a cylindrical body on which an aerodynamics model can be mounted to measure different forces acting on it by aerodynamic loading.**Whetstone bridge card (SCXI-1000**) is a constant DC voltage supply is required to activate the bridges. For this a SCXI-1314 NI card is used which facilitates DC voltage supply. **Data acquisition card (PXI-1033) whichis** the voltage output of the strain gauges is required to be measured under the loading on the balance. For this a data acquisition card PXI-1033 with maximum of 16 voltage input channels is used. Also Labview software facilitated to provide/acquire the input/output voltage signals to/from the strain gauge bridges using a specially built VI program.Usually, non-dimensionalized raw signal (mV/V_{Ex}) has been saved during the test and analyzed later. A linear least square fit for the variation of the normalized outputs with respects to a particulars load components is obtained.

Our step for doing the experiment

- Setting the model on six component balance in wind tunnel
- No wind experiment when no air flow over aircraft model
- Wind test experiment when air flowing over aircraft model in wind tunnel
- calculation of aerodynamic coefficients in body as well as in wind axis

Sign Convention

In general, right hand rule or Euler's convention is followed for all the axes system. Direction of positive forces and moments in body and wind axes are shown in the figure2.

Axes:

x-axis	:	positive forward,
y-axis	:	positive to starboard
z- axis	:	positive downward

Forces in model axes:

Axial force	:	A
Side force	:	Y
Normal force	:	N

Moments in model axes:

Rolling moment, l	:	starboard wing down
Pitching moment, m	:	nose up
Yawing moment, n	:	nose towards starboard

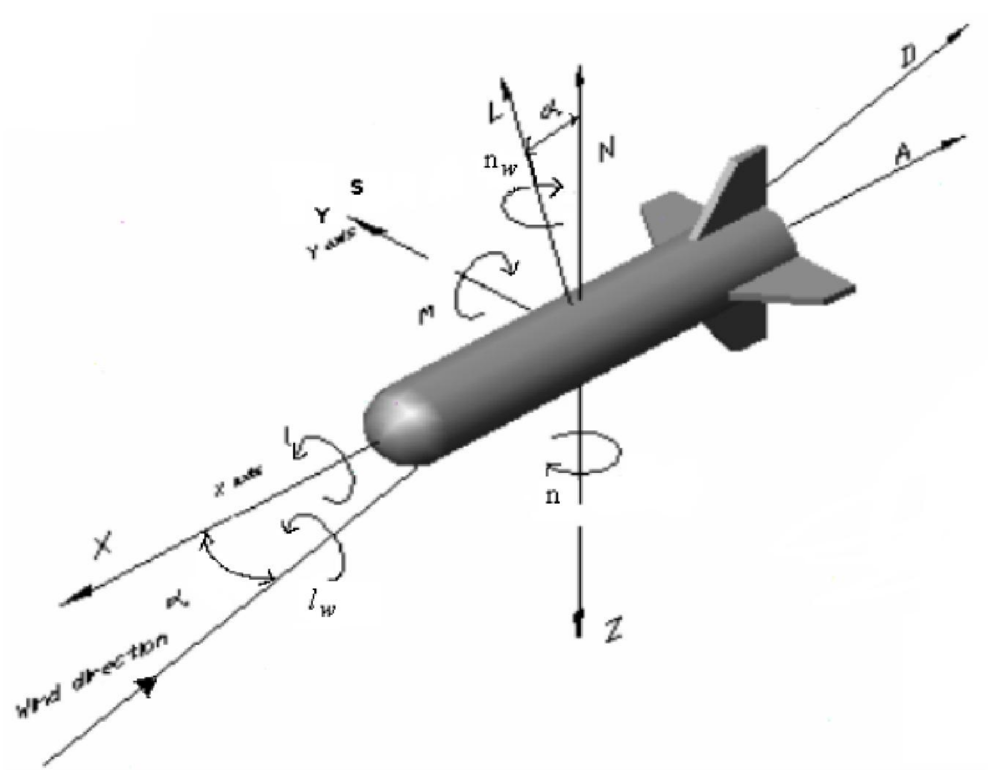

Figure 2: Axes, forces and moments sign convention for body and wind axes

<u>Forces in wind axes</u>:

Drag force, D	:	along the wind direction
Side force, S	:	to starboard
Lift force, L	:	Normal to wind direction

<u>Moments in wind axes</u>:

Rolling moment, l_w	:	starboard wing down
Pitching moment, m_w	:	nose up
Yawing moment, n_w	:	nose towards starboard

Therefore, the relations of forces at balance, body and wind axes with right handaxes convention are as follow

$$\vec{F}_b \begin{bmatrix} F_{Xb} \\ F_{Yb} \\ F_{Zb} \end{bmatrix} = \begin{bmatrix} -A_{xb} \\ Y_b \\ N_b \end{bmatrix}, \quad \vec{F}_B = \begin{bmatrix} F_{XB} \\ F_{YB} \\ F_{ZB} \end{bmatrix} = \begin{bmatrix} -A \\ Y \\ -N \end{bmatrix} \text{ and } \vec{F}_w = \begin{bmatrix} F_{Xw} \\ F_{Yw} \\ F_{Zw} \end{bmatrix} = \begin{bmatrix} -D \\ S \\ L \end{bmatrix} \qquad (1)$$

Subscript 'b' stands for balance axes, 'B' stands for body axes and 'w' for wind axes

Moment components are consistent with the positive convention of the axes. Thus, equations for moments in the balance, body and wind axes will be

$$\vec{M}_b = \begin{bmatrix} M_{Xb} \\ M_{Yb} \\ M_{Zb} \end{bmatrix} = \begin{bmatrix} Mr_b \\ Mp_b \\ My_b \end{bmatrix}, \quad \vec{M}_m = \begin{bmatrix} M_{XB} \\ M_{YB} \\ M_{ZB} \end{bmatrix} = \begin{bmatrix} l \\ m \\ n \end{bmatrix} \text{ and } \vec{M}_w = \begin{bmatrix} M_{Xw} \\ M_{Yw} \\ M_{Zw} \end{bmatrix} = \begin{bmatrix} l_w \\ m_w \\ n_w \end{bmatrix} \qquad (2)$$

The angles are measured w.r.t wind axis and clockwise rotation from reference axis to the target axis is considered positive.

Data Analysis

The balance data analysis involves calculation of aerodynamic coefficients in body as well as in wind axis. These analyses involve transformation from one coordinate systemto another, with origin of the two systems involved in transformation to be coinciding andalso, transfer of forces and moments from a point in the reference axes to another point inthe target axes.

The balance data analysis sequence thus, involves calculation of balance components using the balance calibration coefficient matrix 'Cij' and balance signal. The equation involved is

$$\vec{F}_i = C_{ij}\vec{E}_j$$

where, $F_i = \{Ax, N_1, N_2, S_1, S_2, Rm\}$ and $E_j = \{E_{Ax}, E_{N1}, E_{N2}, E_{S1}, E_{S2}, E_{Rm}\}$

The forces and moments are evaluated at the balance center using equations given below

$$A_{xbc} = A_x \qquad Rm_{bc} = Rm$$
$$S_{bc} = S_1 + S_2 \qquad Mp_{bc} = (N_1 - N_2)\times d$$
$$N_{bc} = N_1 + N_2 \qquad My_{bc} = (S_1 - S_2)\times d$$

where, d is the distance from balance center to normal force or side force gauges.
From the balance center, transformation is done to body or model axes, aligning the force arms of the two axes using following equation

$$\vec{F}_B = T_b^B \vec{F}_b \tag{3}$$
$$\vec{M}_B = T_b^B \vec{M}_b \tag{4}$$

where, $\vec{F}_B$ and $\vec{F}_b$ denote force vectors and the suffix indicates the model and balance axes system respectively. Similarly, $\vec{M}_B$ and $\vec{M}_b$ denote moment vectors. 'T_b^B' is the transformation matrix given as

$$T_b^B = \begin{bmatrix} \cos\alpha_o \cos\psi_o & \cos\alpha_o \sin\psi_o & -\sin\alpha_o \\ (\sin\phi_o \sin\alpha_o \sin\psi_o - \cos\phi_o \sin\psi_o) & (\sin\phi_o \sin\alpha_o \sin\psi_o + \cos\phi_o \cos\psi_o) & (\sin\phi_o \cos\alpha_o) \\ (\cos\phi_o \sin\alpha_o \cos\psi_o + \sin\phi_o \sin\psi_o) & (\cos\phi_o \sin\alpha_o \sin\psi_o - \sin\phi_o \cos\psi_o) & (\cos\phi_o \cos\alpha_o) \end{bmatrix}$$

Here the angles are the offsets between the balance and the body.
The forces and moments are then transferred to a reference point (e.g. CG of themodel) in the body axes. During the transformation, forces remain same, whereas themoments are changed due to displacement vector. The following equations are used forthe moment calculation.
If point 1 is balance center and point 2 is the reference point in model and a systemof forces produces a resultant force $\overline{F1}$ and a resultant moment $\overline{M1}$ relative to point 1 then the equivalent system acting at another point 2 is

$$\vec{F}_2 = \vec{F}_1$$
$$\vec{M}_2 = \vec{M}_1 - \vec{r}_{12} \times \vec{F}_1$$

Thus,

$$\vec{M}_2 = (iM_{x1} + jM_{y1} + kM_{z1}) - \vec{r}_{12} \times \vec{F}_1$$
$$= \hat{i}\left[M_{x1} - (\Delta y F_z - \Delta z F_y)\right] + \hat{j}\left[M_{y1} - (\Delta z F_x - \Delta x F_z)\right] + \hat{k}\left[M_{z1} - (\Delta x F_y - \Delta y F_x)\right]$$

Therefore, the final equations of the moment about the three axes for model are

$$l = M_{xB} = M_{xb} - (\Delta y F_{zb} - \Delta z F_{yb})$$

$$m = M_{yB} = M_{yb} - (\Delta z F_{xb} - \Delta x F_{zb})$$

$$n = M_{zB} = M_{zb} - (\Delta x F_{yb} - \Delta y F_{xb})$$

Thus, from equation 3 and 4, forces and moments are calculated and coefficients areevaluated at the model reference point. Equations for force coefficients are

$$C_A = \frac{A}{qA},\ C_Y = \frac{Y}{qA} \text{ and } C_N = \frac{N}{qA}$$

And for moments coefficient

$$C_l = \frac{l}{qAs},\ C_m = \frac{m}{qAs} \text{ and } C_n = \frac{n}{qAc}$$

A similar kind of transformation is done to get forces and moments with respect to the wind axes from the model (body) axes..

Suggested works:

- Draw the schematic of six component force balance calibration setup and describe the calibration procedure in details.
- Write the equations for evaluating the orthogonal forces and moments at the force balance center acted upon by a random force.
- Write the equations for real orthogonal forces and moments acting on a model (attached to the force balance) at a reference point by a random aerodynamic force in terms of loads measured by the force balance.
- Discuss what you have understood from this experiment.
- Calculate the dimensional less , ~~drag~~ force , and moment coefficients about the wind axes.

Questions:

1) What are the different aerodynamic forces acting on a model?
2) What are the working principles of this force balance?
3) What are the other types of balances?
4) What are the advantages and disadvantages of mechanical balance compared to strain gage type?
5) Why we do no wind analysis in force measurement experiment.

References:

1) Low-speed wind tunnel testing - W. E. Rae, Jr. and Alan Pope.
2) Fundamental of Aerodynamics - J. D. Anderson.
3) Wind-tunnel technique - R. C. Pankhurst and D. W. Holder
4) Wind-tunnel testing - Alan Pope

5) Low-speed wind tunnel testing - W. E. Rae, Jr. and Alan Pope
6) High-speed wind tunnel testing - Alan Pope and K. N. Goin
7) Aerodynamics test facilities - T. N. Krishnaswamy
8) Fundamental of Aerodynamics - J. D. Anderson
9) Boundary layer theory - H. Schlichting